ANALYTICAL STUDY ON EFFECTS OF TIDE ON STORM SURGE DEVIATIONS

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INTRODUCTION

Elucidating the mechanism of storm surge generation and gaining new knowledge is important for the advancement of numerical simulations and the consideration of disaster prevention measures. Previous studies have shown that even when the external forces (wind and pressure) of a typhoon are the same, the storm surge deviations generated change when the tidal phase at the time the typhoon strikes is different. This is because the difference in the tidal phase causes a change in water depth. The conventional equation (Equation (1) shown below) can be used to understand the rough variation characteristics of storm surge deviation, but no quantitative study has been conducted.

$$\eta=\frac{\tau F}{\rho g h} \quad (1), \qquad \eta=\frac{\tau F}{\rho g h_H}\tanh^{-1}\left(\frac{h_H}{h}\right) \quad (2)$$

η : Storm surge deviation (m) , τ : Wind stress (N/m^2) , F : Fetch (m)
ρ : Sea water density (km/m^3) , g : Acceleration of gravity (m/s^2)
h : Average water depth (m) , a : Sea-bottom gradient , $h_H=aF/2$

In this study, we quantitatively examined the change in storm surge deviation with water depth and derived an analytical solution that is more accurate than the conventional equation (Eq. (1)). Subsequently, parameters indicating the effect of changes in water depth on storm surge deviation were derived, and the characteristics of major bays in Japan were examined using these parameters.

INVESTIGATION OF DEPENDENCE OF STORM SURGE DEVIATION ON WATER DEPTH VARIATION DUE TO TIDE

Storm surge simulations in the Ariake Sea in Japan were performed using an unstructured grid ocean model. Figure 1 shows the computational mesh and typhoon setup conditions. The left panel of Fig. 2 shows the change in the maximum storm surge deviations at point A in Fig. 1 by varying the tidal phase for the storm surge peak. The deviation at low tide is more than 1 m larger than at high tide. This is because the water depth h becomes shallower at low tide, as can be seen from Eq. (1), resulting in a larger deviation η. However, substituting a typical value for the Ariake Sea into Eq. (1), the change is several tens of centimeters (blue line in the right panel of Fig. 2), which is much smaller than the result of the numerical experiment. We focused on the spatial distribution of water depth as the reason for this. Although the water depth h in Eq. (1) is constant, in reality, as shown in Fig. 1, the water depth in the Ariake Sea is smaller closer to the inner part of the bay. Therefore, we took the seafloor gradient into account and derived Eq. (2). According to the equation, the difference in deviations between high and low

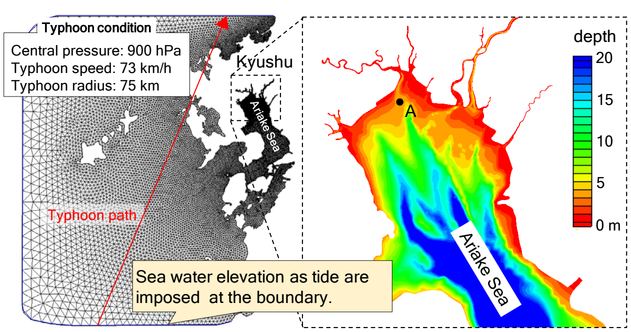

Figure 1 - Computational mesh and typhoon condition

tides is almost twice the value obtained by Eq. (1) (red line in the right panel of Fig. 2). This result is in quantitative agreement with the results of numerical experiments. Thus, even when the spatial mean depth is the same, the storm surge deviations differ greatly depending on the difference in seafloor gradient. Therefore, seafloor gradient is important to accurately discuss storm surge deviation.

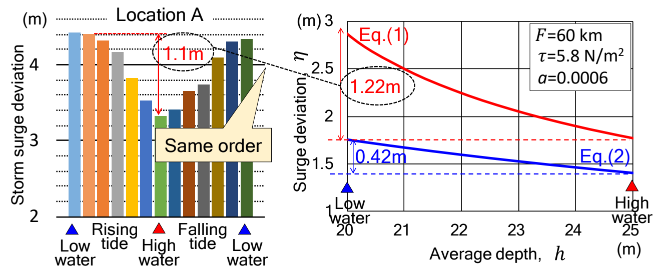

Figure 2 - Maximum storm surge deviations in (left) numerical simulations and (right) analysis solutions

PARAMETERS OF EFFECT OF SEAFLOOR GRADIENT ON STORM SURGE DEVIATIONS

The effect of seafloor gradient on storm surge deviations was examined using analytical solutions. The effect of seafloor gradient can be expressed by E (Eq. (3)) derived from Eq. (2). Table 1 shows the values of E for major bays in Japan. It can be seen that E is large (about 1.5) in the Ariake Sea and Tokyo Bay. This means that the storm surge deviation is 1.5 times larger than when the seafloor is flat. Even the smallest E in Ise Bay is about 1.2. From the above, it can be seen that the storm surge deviations occurring in major bays in Japan are considerably affected by the seafloor gradient.

$$E=\frac{h}{h_H}\tanh^{-1}\left(\frac{h_H}{h}\right) \quad (3), \qquad I=\frac{F}{h}\frac{1}{1-(h_H/h)^2} \quad (4)$$

Table 1 - Parameters in major bays of Japan

	Ariake Sea	Tokyo Bay	Osaka Bay	Ise Bay
E	1.55	1.54	1.34	1.21
I	12.32	7.69	4.51	2.01

EFFECT OF WATER DEPTH VARIATION ON CHANGE IN STORM SURGE DEVIATIONS

The parameter I in Eq. (4) represents the effect of the change in water depth on the change in storm surge deviation. In other words, a larger I means a larger change in storm surge deviation due to tidal water depth change. In Table 1, I is the largest in the Ariake Sea, while it is small in Ise Bay. Thus, the impact of water depth variation on storm surge deviations varies greatly depending on the sea area.

CONCLUSIONS

This study clarified the effects of water depth variations on storm surge deviations quantitatively using numerical simulations and analytical solutions. The seafloor gradient is an important factor in quantitatively discussing storm surge deviations. Furthermore, we derived new parameters indicating the effects, and the characteristics of major bays of Japan were revealed by using the parameters.